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HF Radar as a Fleet Sensor

[Unclassified Title]

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with Appendices by
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Radar Division

June 1970

DEPARTMENT OF THE NAVY NAVAL RESEARCH LABORATORY

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ABSTRACT
(Secret)

(S) Aircraft, ship, and clutter echoes have been studied using surface-wave propagation on the Chesapeake Bay. These studies show that coherent pulse doppler methods can be used for surface target detection. Required radar features for several applications can be estimated.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

NRL Problem 53R02-49
NSSC Task SF11-141-004-14605

HF RADAR AS A FLEET SENSOR (U)

(S) This is an interim report on NRL Problem 53R02-49 which is sponsored by NAVSHIPS. Most of the material (except for corrections) appeared in a Technical Memorandum of the same title issued 4 August 1969 and in the ARPA Technical Review of 1969 under the title of "Some Ground Wave Tests." The concept of remote sky-wave illumination of targets and bistatic ground-wave detection was originally prepared for the Missile-Threat Ship Defense Study Group and appears in Appendix B, "Detection and Threat Assessment," of this Group's report (secret document) dated November 27, 1968.

I. INTRODUCTION (U)

(S) The Navy need for an OTH sensor has been recognized f-r some time.[1,2] This paper describes work with HF radar intended to study its application as an over-the-horizon sensor for fleet units. The tasks may be defined as follows:

1. Demonstrate the feasibility of monostatic surface-wave radar against aircraft SSM's and ASM's.

2. Determine requirements in HF radar design and better define HF radar capability and potential for naval application.

(S) By way of background, NRL was assigned this problem because of:

1. Possession of more than a decade of sky-wave HF radar experience.

2. Existence at NRL of the necessary high-power transmitters, frequency and modulation synthesizers, receivers, and doppler signal-processing equipment to start the task.

(S) The reasoning was that if the following steps were taken, the equipment on hand would be suitable for a basic feasibility study, and the study could be implemented and conducted with a modest investment:

1. Add an antenna suitable for launching a surface wave down the Chesapeake Bay

2. Improve the short-range performance of the receiving equipment

3. Develop a duplexer switch with a recovery time sufficiently short.

(S) The equipment additions and improvements have been carried out sufficiently to allow a series of measurements to be made. The basic feasibility of monostatic surface-wave radar to provide over-the-horizon detection of airborne targets has been demonstrated. In addition, a capability for

detection of surface targets down to a slow speed has been found. It is possible now to develop at least a preliminary design of a shipborne HF radar, although a number of areas could benefit from more study.

(S) First tests of the bistatic, sky-wave, ground-wave concept have been accomplished. The aim is to provide over-the-horizon sensing for "quiet" fleet units.

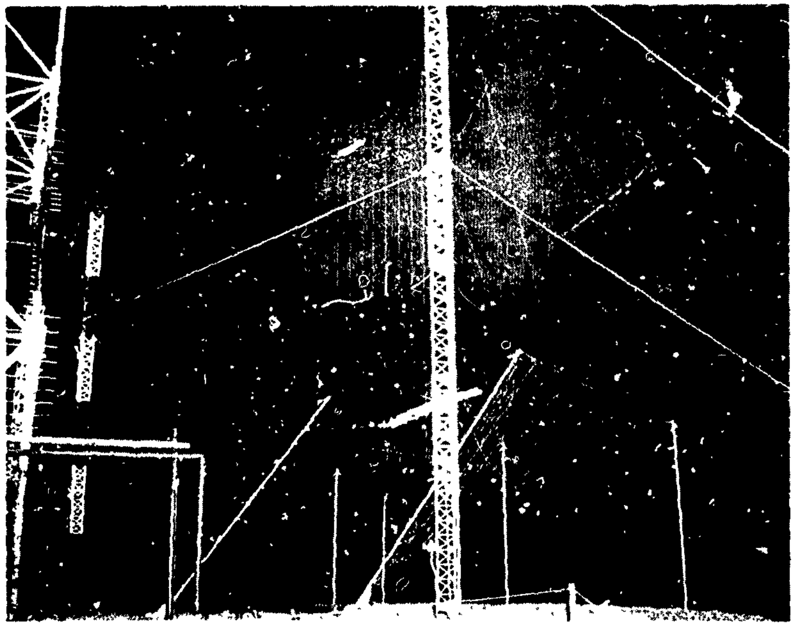
(U) In the following sections the radar equipment will be described and the test results will be shown and discussed.

II. EQUIPMENT (U)

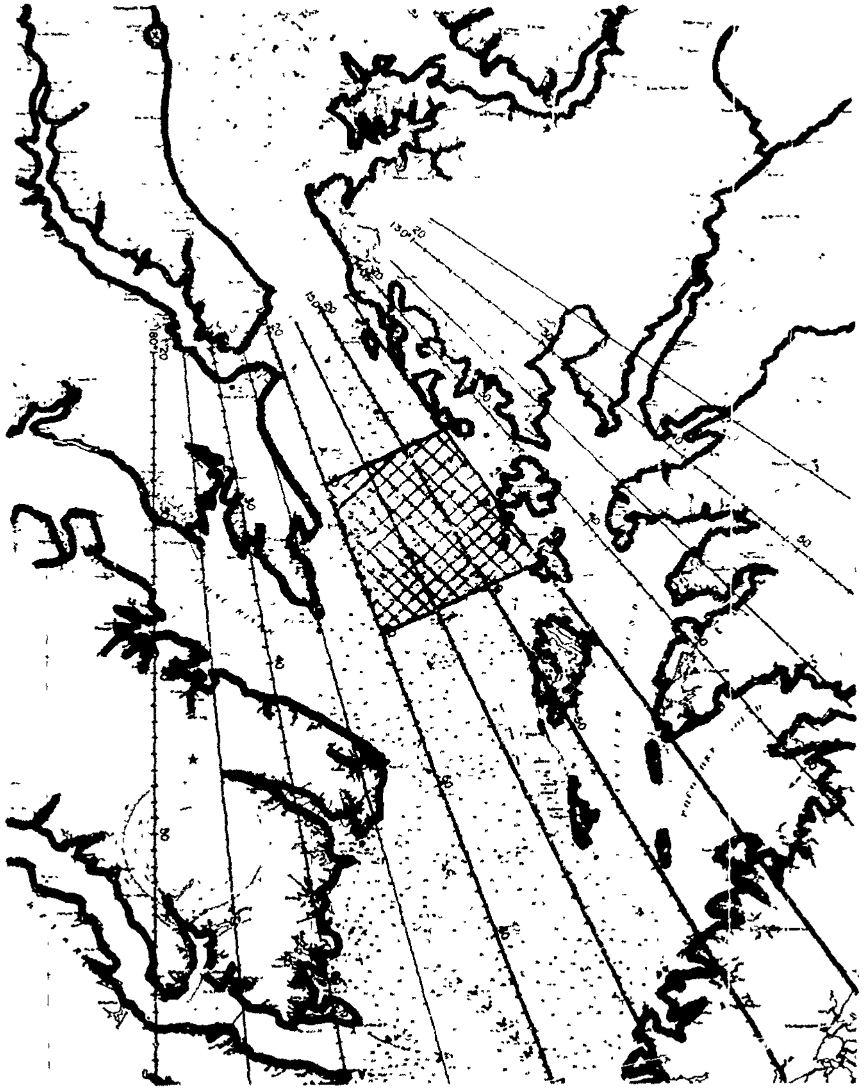
(U) The major procurement was an antenna suitable for surface-wave tests. The antenna is an ITT-Electrophysics Lab design that consists of two broadband monopoles (Folded Triangular Monopoles or FTM's) backed by a reflecting curtain. The emphasis was on obtaining an antenna sufficiently broadband for the desired tests that would launch a good proportion of its energy at low elevation angles. The antenna was by no means visualized as a shipborne prototype; it was obtained as an inexpensive radiator, satisfying minimum necessary requirements that promised a quick delivery. The antenna is on the bluff at CBD, and its picture is shown in Figure 1a. It looks down the Bay as shown in Figure 1b. A typical surface-wave illumination cell is shown cross-hatched in Figure 1 where the angular extent has been estimated from the confines of the water path - not the antenna beamwidth - and the cell-range extent is determined from the 8-kHz sample rate commonly used. Some of the characteristics of Chesapeake Bay can be derived from Refs. 3 and 4, as is done in Appendix A.

(U) The already existing equipment included a 100-kw average, 5-Mw peak linear amplifier, and low-level signal synthesis such that transmitter frequency, calibration signal frequencies, and all signals injected into the receiver chain for frequency translation are derived from a single standard. Linearity is an important feature in pulse-doppler signal handling, and this is an area that required improvement for the surface-wave tests. Figure 2 is a simplified block diagram of the current configuration. Briefly, the signal processor used in the tests, described below, is a doppler frequency analyzer with over 60-dB linear dynamic range before detection.

(C) Figure 3 shows schematically the duplexer switch that was developed to permit operation for the short time delays required for surface-wave radar when receiving. The diodes are biased off with 200 volts, and when transmitting, a forward bias of 30 amps per switch is applied. There are two back-to-back diode pairs in each of the four switches that are used in the hybrid duplexer network. The inductance resonates with the diode capacitance at midband - that is, $f = \sqrt{10 \times 27}$ MHz. The goal achieved is a recovery time of 70 μs and an insertion loss of 0.6 dB. Figure 4 is a picture of one diode mount that plugs into the 9-inch coax. Reference 5 contains a more detailed description of the equipment.



(a)



(b)

Figure 1 - (a) FTM antenna (b) surface-wave path with a typical resolution cell (U)

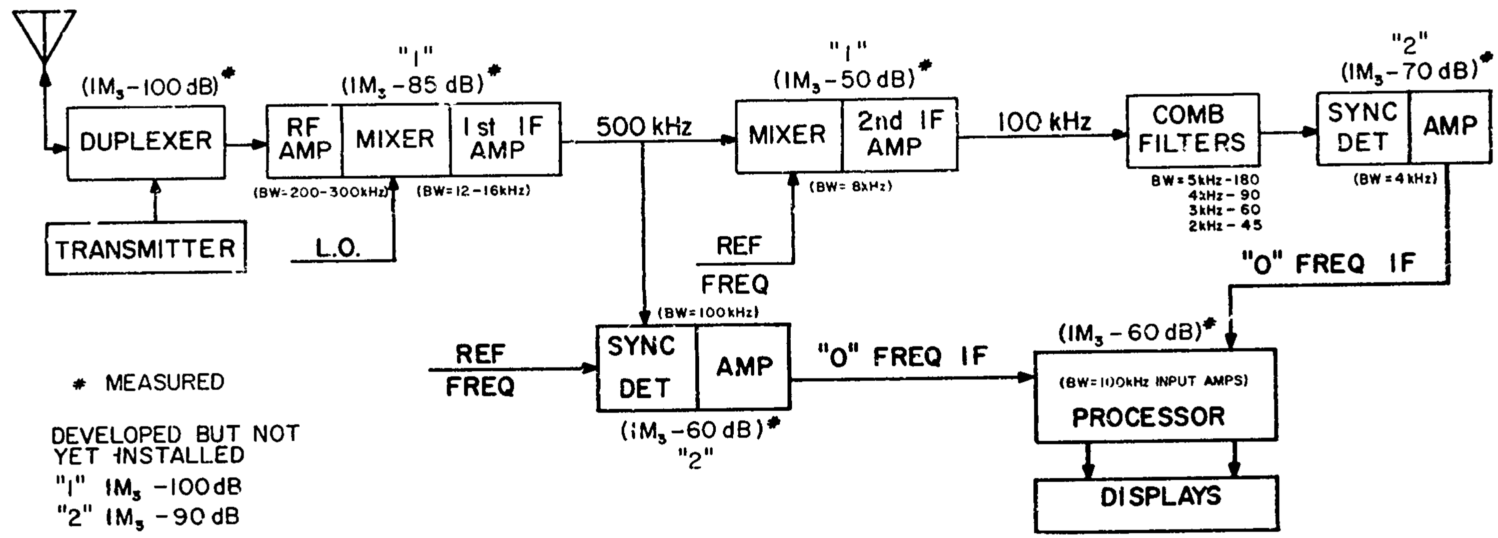


Figure 2 - Diagram of radar with dynamic-range limitations noted. The third-order intermodulation-product level (IM_3) below the test signals is the measure. (U)

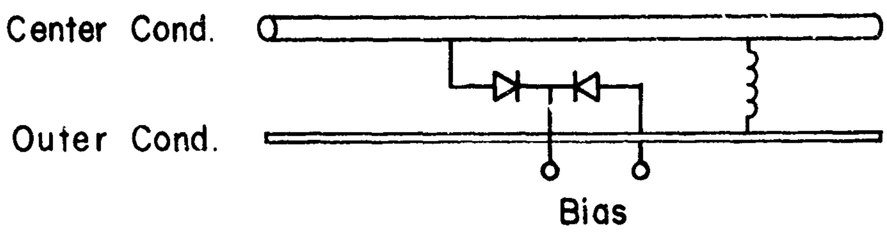


Figure 3 - Schematic of the duplexer switch (C)

III. SHIP AND AIRCRAFT TEST OF 11/27/68 (U)

(S) A set of display pictures with a description will help illustrate the environment in which the surface-wave radar exists. The pictures of Figure 5 were taken in real time while a controlled aircraft was flying up and down the Chesapeake Bay. Although an 8-kHz sample rate was used on this day, other bandwidth restrictions caused the half-power-point range cell to be 20 nmi. The pictures marked 1530 and 1540 GMT are of the receiver IF, and show signal level at the antenna terminals in millivolts versus range in nautical miles. The responses seen out to 70 nmi are of ground wave and line-of-sight fixed targets and aircraft. The strong signal at 230 nmi is a direct reflection (vertical sounding) from the F_2 layer of the ionosphere. Ground clutter seen via sky wave starts at about 400 nmi and continues with range as far as is shown. It was decided to operate with no confusion due to second-time-around sky-wave clutter; a PRF of 45 Hz initially permitted this. The picture with doppler, f_d, given as a function of range, R, is a typical view of doppler-range space (doppler in Hertz and range in nmi). The large blob around zero frequency running from 0 to 80 nmi in range represents echoes from fixed targets and the Bay surface. The signal at +10 Hz and 100 nmi is a reference signal. All of the rest of the targets are of aircraft, probably seen by line of sight. At the upper right of the figure are two range-gated doppler-vs.-time pictures where 1825 designates the time the picture was taken, and past time is shown back through 200 seconds. The time 1825 GMT coincides with the time the doppler-range picture was taken. Examination of the right edge of the doppler time marked RG 50-70 nmi (a range gate centered on 60 nmi) reveals the coincidence between targets at 60 nmi on the lower left and upper right displays. The doppler filter was 0.15 Hz, as indicated by BW 0.15. The doppler-time picture at the lower right was made about an hour and a half later, after the filter bandwidth had been reduced to 0.07 Hz, the doppler extent reduced, and the doppler scale expanded. The line at zero is seen to have actually been the two lines - maybe three, one at zero, one at approximately +0.3 Hz, and possibly one at -0.3 Hz. All of the flecks with negative doppler are from sky-wave clutter that began coming in, folded around zero range. The PRF was

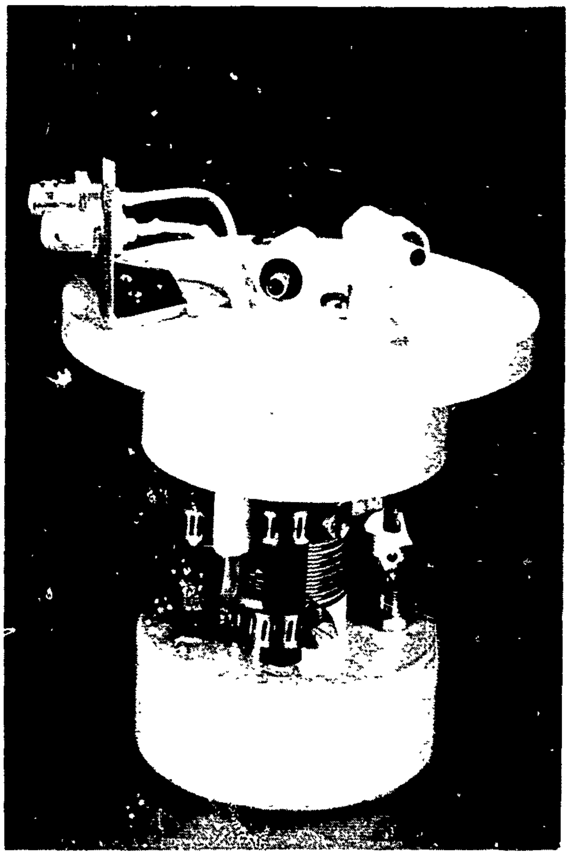


Figure 4 - Duplexer diode mount (C)

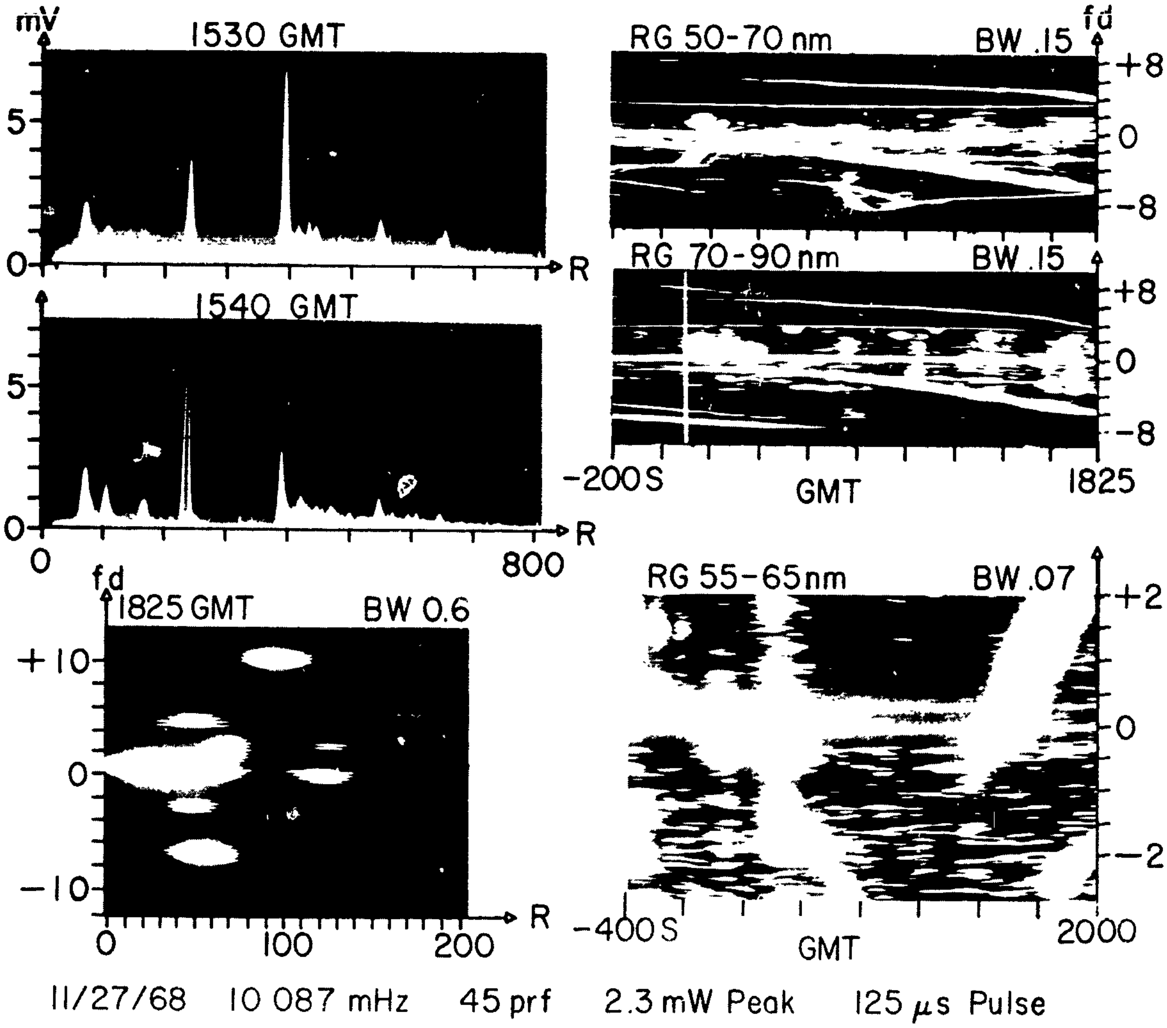


Figure 5 - Earth backscatter and aircraft echoes (S)

reduced to 22-1/2 and the pictures of Figure 6 made. The picture in the upper left is of a range gate (20 nmi wide at the 3-dB points) centered on 40 nmi, and the ordinates are doppler in Hertz versus time in seconds before 20:10 GMT. The lines at plus and minus about 0.3 Hz are from the resonant gravity waves, approaching and receding normal to the look direction. The line at zero represents fixed target returns. The line at +1.5 Hz is a reference signal that was placed in that range gate. The line at +0.6 Hz is from a moving target, identified by our airplane as the cargo ship Bethtex. About an hour later an amplitude doppler analysis was made at this same range gate and it is shown in the upper right picture. Amplitude is given in microvolts and the doppler scale has been indicated in knots. By this time the Bethtex was getting out of the range gate, but its echo can still be seen at +16 knots. The approach and recede resonant wave echoes are evident at about plus and minus 8 knots with the approach ones being the stronger. This fits with the prevailing wind that was observed as coming from the south. At this time some equipment modifications were made such that steps could be made in the range gate. For the picture at the middle left the range gate was first stepped out to 50 nmi; the period for this range gate was 20:14:00 minus 400 seconds, to 20:14:00 minus 320 seconds. Only approach resonant-wave and fixed targets are evident. Upon stepping the range gate back to 40 nmi the Bethtex again appears, weaker no doubt because it was proceeding toward us and out of that range gate. Also the receding resonant wave echoes reappear. The middle picture on the right made 44 minutes later (21:58 GMT) shows first the view at a 30-nmi range gate and then at 21:58:00 minus 270 seconds a 20-nmi range gate starts. By this time, one hour and 48 minutes from the picture of upper left, the cargo ship is strongest in the 20-nmi range gate; this is consistent with its speed. Note that in this last range gate a ship going down the Bay appears with a doppler smaller than that of the recede resonant waves. The last doppler-time picture, lower left, is a slightly later (4 minutes) view of the 20-nmi range gate. An accelerating aircraft track can be seen wandering through the picture. At 22:02:00 minus 14 seconds another amplitude-versus-relative-speed analysis was made and it is shown as the picture at the lower right. From left to right the targets (all clipped at the top) are identified as receding resonant waves, ship going down the Bay, fixed targets, approaching resonant waves, and the approaching ship. The resonant-wave echoes may have a slightly wider spectrum than the other returns, but it is not too evident from this picture. This latter set of observations were made with modest power (5 kw average) and constitute a demonstration that surface-wave radar can detect surface targets. If slow-target detection is desired, periodic shifts in operating frequency could be used to shift the speeds obscured by resonant wave echoes.

IV. ECHOES FROM THE BAY SURFACE (U)

(U) Backscattered signals from the Bay surface constitute the most available radar target for ground-wave-propagation demonstration. Figure 7 gives a set of radar displays in the range-gated amplitude-vs.-doppler format. The 10-mile range gate was centered on 33 nmi. For the 10.087-MHz display the fixed targets (banks of the Bay, etc.) are prominent at the

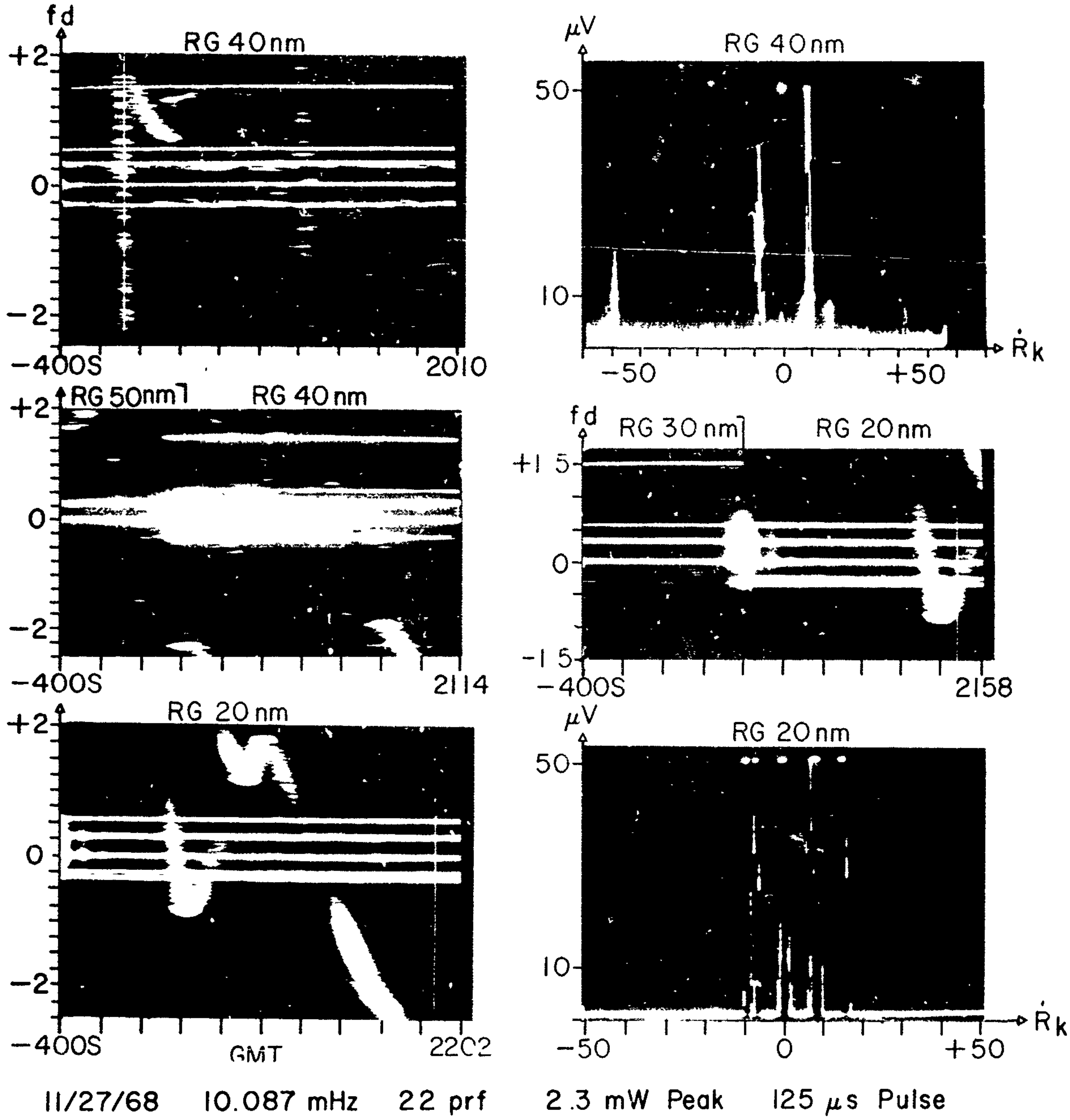


Figure 6 - Resonant wave and ship echoes (S)

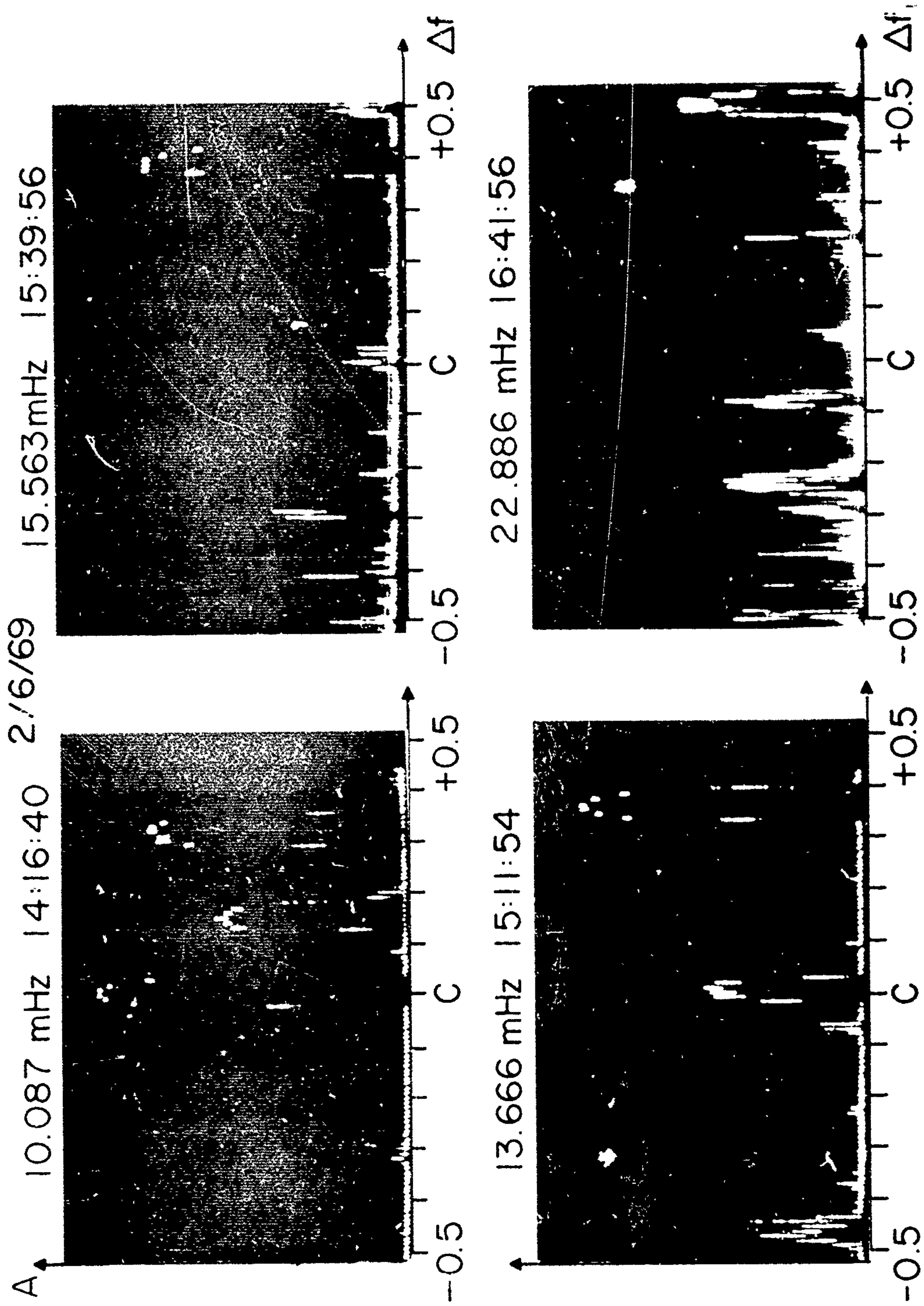


Figure 7 – Range gated, amplitude versus doppler frequencies displays. (U)

carrier frequency, C; the approaching resonant-wave echoes can be seen at a little above +0.3 Hz doppler; the receding resonant waves are just discernible at a little less than -0.3 doppler, although it just happens that this picture was taken during a brief low-amplitude interlude; and a ship echo can be seen at +0.16 Hz (about 5 knots). The other pictures are for operation at other, higher frequencies. The approaching resonant-wave echo is visible in all displays, and the behavior can be predicted as shown by the curve marked $\sqrt{g/\pi\lambda}$ in Figure 8. This curve gives the phase

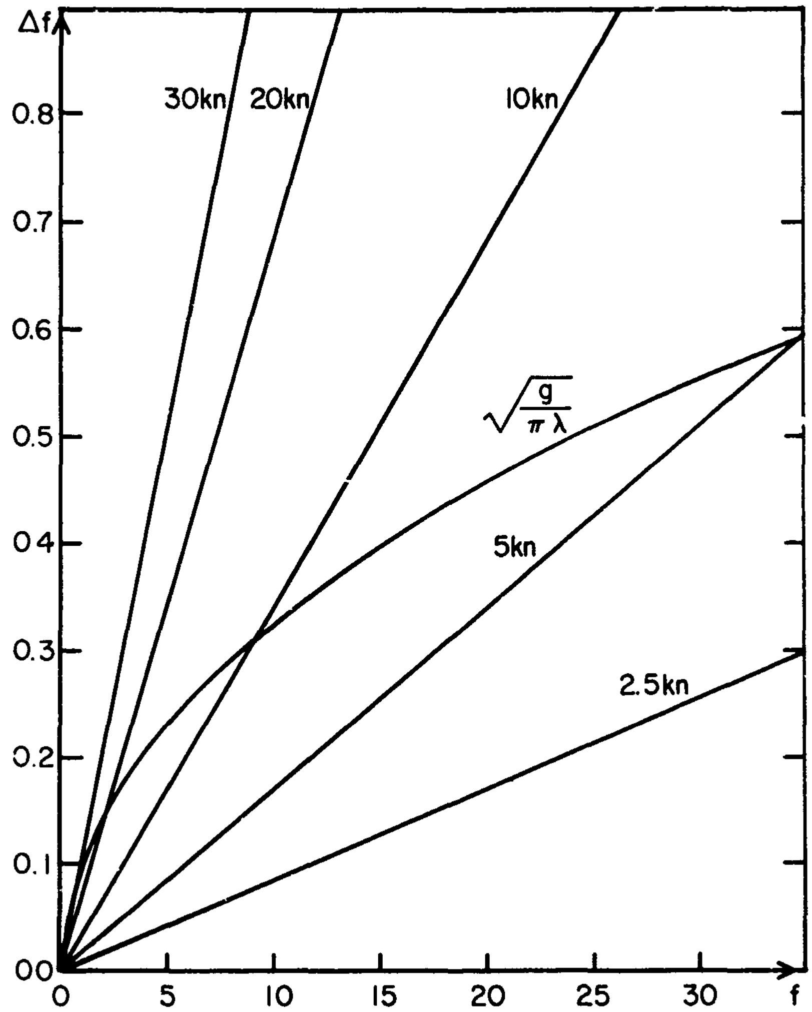


Figure 8 - Doppler frequency (Hz) versus operating frequency (MHz) (The straight lines are for any moving target in knots, while the curved line is for gravity waves.) (U)

velocity of gravity waves with a $\lambda/2$ spacing, where λ is the radar wavelength. Evidently the principal water surface echo comes from wave trains proceeding directly toward and away from the radar. This behavior, where the sea echo is almost duochromatic, permits doppler detection of targets at almost any speed.

(U) Figure 9 is an amplitude-vs.-range plot made with a narrow doppler filter showing the approaching resonant waves (ARW at 0.315 Hz), receding resonant waves (RRW at -0.315 Hz), fixed targets (FT at 0.00 Hz), and two ship targets (T at 0.270 Hz and T at 0.150 Hz). Figure 10 is a similar analysis made on a different day with less transmitted power. Note that the fixed targets appear to have about the same amplitude from one test to the next when the difference in transmitted power is considered. It is felt that the echoing area of the fixed targets (FT) is probably relatively constant, and that the FT can be used as a reference to determine the extent to which path loss may be a function of surface state. The difference in amplitude order of the approach and recede resonant wave echoes fits the noted wind direction on these two days. During the tests of 2/4/69 there was a brisk wind from the north. The condition of the bay surface did not approximate a fully developed spectrum on the open sea; however, it was one of the roughest surfaces noted during observations. The following table can be made, using data from Appendix A and the radar equation:

Range (nmi)	RRW Area (dB/m^2)	Ground-Wave-Illuminated Area in a Range Cell (dB/m^2)	Backscattering Coefficient, σ^o (dB)
45	57	86	-29
55	58	87	-29
67	55	84	-29
75	51	80	-29

Experience with sky-wave radar plus theory(6) suggests that σ^o can often be of the order of -20 dB.

V. S2 AIRCRAFT TESTS, 6/9/69 AND 6/13/69 (U)

(U) For the results that follow a new antenna was used for receiving. The new receiving antenna is a whip monopole located on the Bay surface; its features are given in Appendix B. This antenna was erected to permit the calibration of the FTM pair and to provide an antenna more selective to vertically polarized signals. The FTM's, while fulfilling most of the design objectives, do have an appreciable horizontally polarized component for most azimuths. When operating with the FTM antenna there were generally so many strong, horizontally polarized, and line-of-sight echoes from aircraft flying in the area that the relatively weaker ground-wave-propagated returns were severely obscured. The difference in aircraft radar cross section can be 10 dB or larger for horizontal polarization than for vertical.

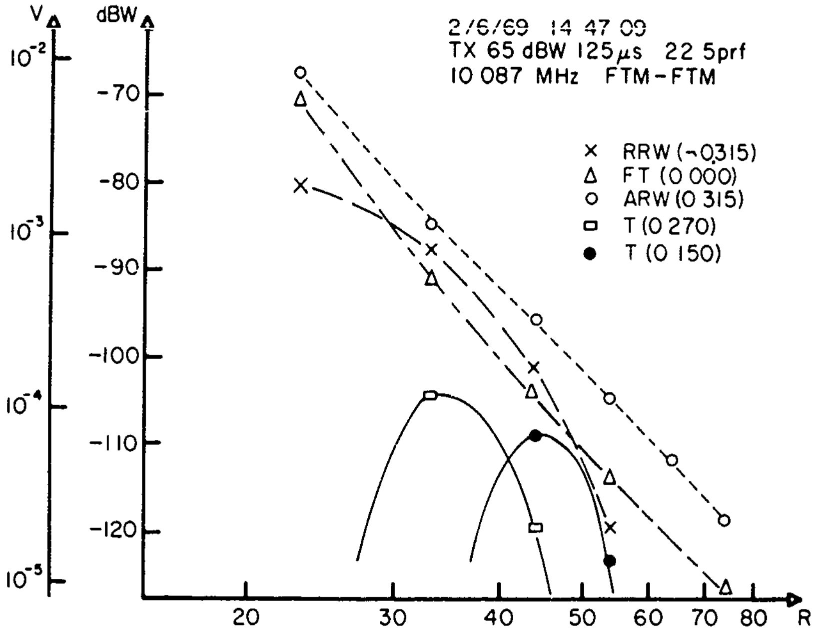


Figure 9 - Received signal versus range (U)

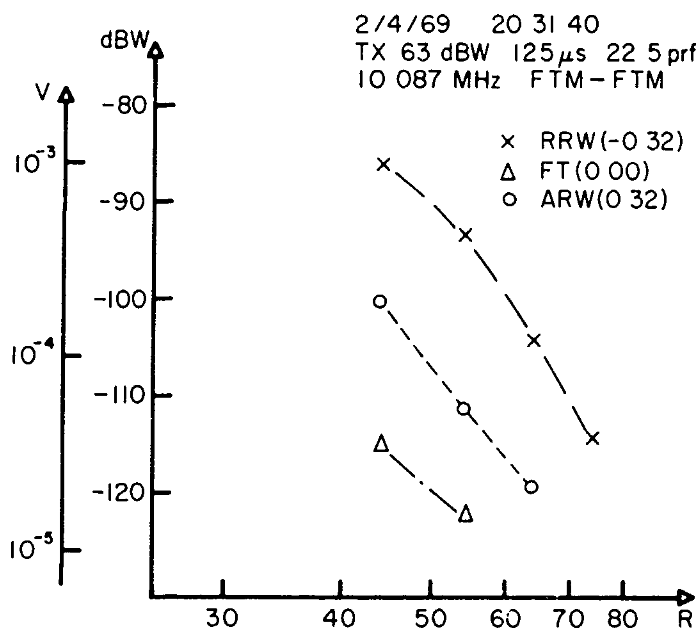


Figure 10 - Received signal versus range (U)

(S) On 9 June 1969 the first controlled aircraft flight using the whip on the Bay (MONO antenna) was conducted. The MONO did reduce the amplitude and number of line-of-sight aircraft echoes and it was possible to identify the desired target for long periods of time. Figure 11 shows a range-gated doppler-time record made with the S2 aircraft circling at 40 nmi down the Bay at an altitude of 500 feet. For this operating time the placement of the available dynamic range (60 dB) was set by the surface-wave clutter amplitude, and the gain operating point was set so that the clutter in the 40-nmi range gate used the maximum linear amplitude range of the processor. The minimum doppler frequency visibility was controlled by the doppler width of the sky-wave backscatter. In Figure 11 the target track is not very prominent; the doppler function with time is illustrated below the record picture, and the reader should be able to see the "approach" loops between 1525 and 1526, and between 1527 and 1528. Now in real time this target track was easily identified and followed with the aid of pilot-furnished readings for maximum approach and recede doppler. Although the target track is quite elusive in this exhibit, it should be emphasized that the effects of most of the factors that make it so can be eliminated or considerably reduced by radar design. For example, examine Figure 12, a similar display for times 1550 and 1552. Here the amplitude of the received target echo is comparable to or lower than that in Figure 11; however, it is easily seen. The factors contributing to this visibility improvement are lower backscatter levels - both sky wave and surface wave. In Figure 12 the target spiraled up to 8000 feet; both received power and altitude are shown. In both Figure 11 and Figure 12 the numerous doppler lines are from other aircraft in the 10-nmi range gate centered on 40 nmi. Certainly, most of them are line of sight and from aircraft larger than the S2. This undesired target clutter has been more severe when using the FTM for both transmit and receive.

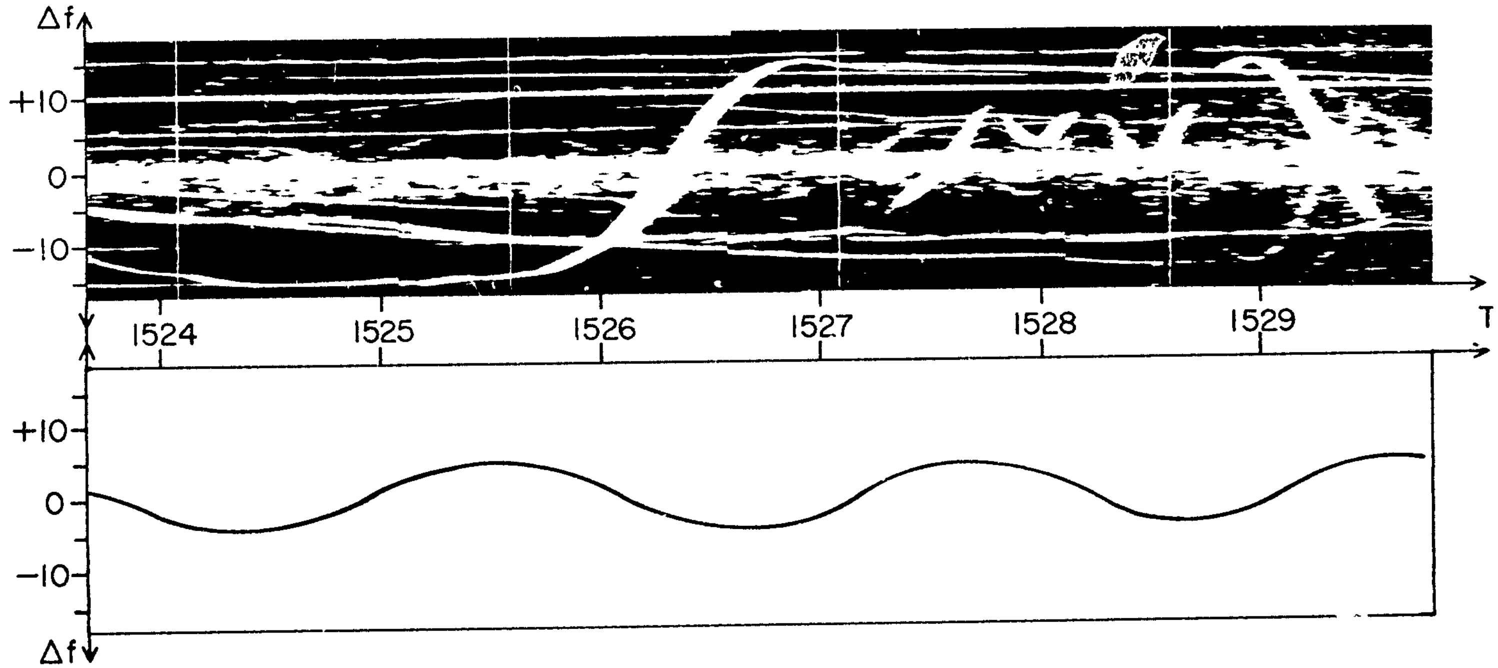
(U) The following relation will be used for target radar cross section:

$$\sigma = \frac{(4\pi)^3 R^4 P_r}{G_t G_r \lambda^2 P_t} \cdot \frac{1}{F}$$

where F is the additional loss over free-space propagation attributable to ground-wave propagation.

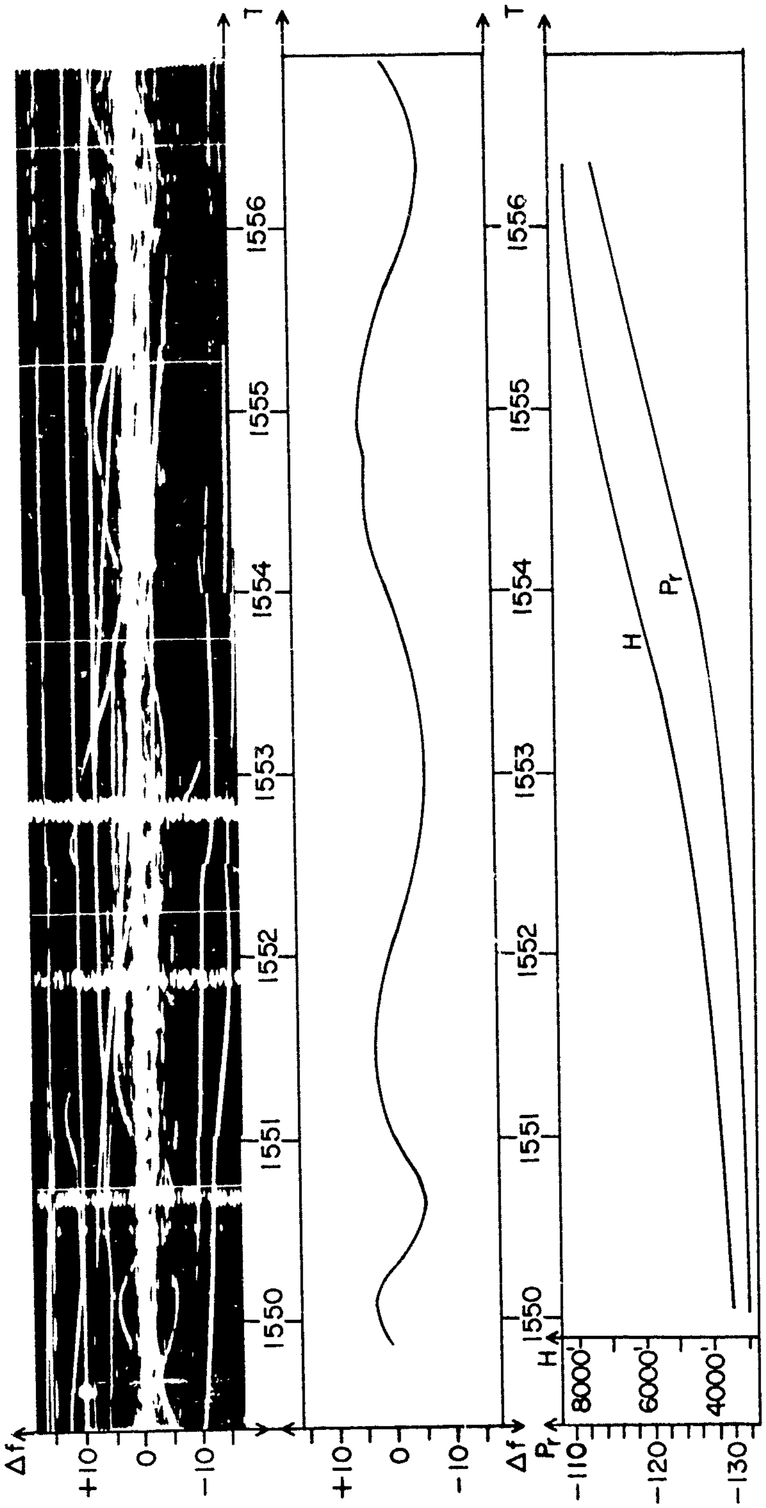
(U) In dB, the following values are used:

$$\begin{aligned} G_t &= 10 \\ G_r &= 5 \\ \lambda^2 &= 29 \\ P_t &= 64 \\ \text{Denominator Total:} \quad & \overline{108} \end{aligned}$$



6/9/69, TX 64/47 dBW, 125 μs, 180prf, 10 087 MHz, H 500'
ANT FTM/MONO, BW $\frac{2000}{14000}$ BESSEL, RG 40 nmi

Figure 11 - A range gated doppler-time display. Test target actual doppler is drawn below. (S)



6/9/69, TX 64/47 dBW, 125 μs, 180 prf, 10 087 MHz, ANT FTM/MONO, BW $\frac{2000}{14000}$ BESSEL, RG 40 nmi

Figure 12 - (a) Range gated doppler-time. (b) Test target doppler.
(c) Received power and altitude test target. (S)

$$(4\pi)^3 = 33$$
$$R^4 = 195$$

Numerator Total: 228

$$\sigma = P_r - F + 120$$

(U) Using F = -24 from Appendix A,

$$\sigma = P_r + 144$$

(S) On June 9, 1969 the following measurements were made on the S2 aircraft while it was at 500 feet altitude:

Received Peak Power (dBw)	Aspect	$\sigma(dB/m^2)$
-130	Accelerating head	14
-127	Tail	17
-124	Head	20

(S) On 13 June a number of head-aspect measurements were made, all being values within 1 dB of -130 dBw. Received powers are plotted versus altitude in Figure 13. The shape of this received power curve is consistent with propagation theory. The received powers obtained when the target was

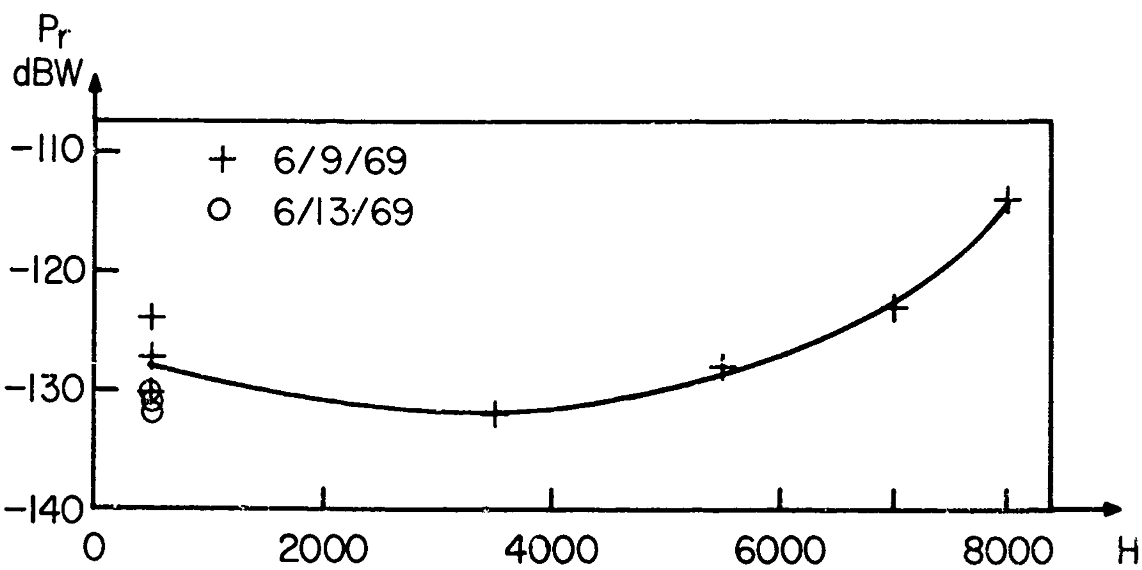


Figure 13 - Received power from test target versus altitude (feet). (S)

at 500 feet yield cross sections from 14 to 20 dB/m^2. In the computations the line loss, from the MONO to the reference-level point, was not taken into account and its inclusion might increase cross sections by a dB or so. Thus these measurements indicate that the S2 possesses a radar area between 25 and 100m^2. The S2 dimensions are:

Tail span	22'5" or 6.84 m
Wing span	69'8" or 21.24 m
Height	16'3" or 4.96 m
Length	42'3" or 12.88 m

These dimensions are appreciably larger than may be expec ed for an SSM or ASM - perhaps 10 dB larger in radar area. Despite the submarginal appearance of the record of Figure 11, the detection would have looked good if the target had possessed considerably higher speed, or if the radar system could have been operated optimally and with a lower PRF. Remember that the minimum detectable signal was clutter-level-limited - not noise limited - and that the effective processing time for the circling target was short. It is estimated that a radar that was properly designed (and realizable) could detect an approaching missile at the 40-nmi distance. If the operation is extrapolated to the ocean where the conductivity is 4 mho/m or greater, this detection range translates to about 50 nmi.

VI. BISTATIC TEST, 4/15/69 (U)

(S) Some first measurements have been made using sky-wave illumination of the target and propagation from the target to the receiver by surface wave. The transmitter (courtesy of ITS of ESSA) was near Boulder, Colorado (1370 nmi distant), the receiving antenna was the MONO. The transmitted power was about 25 kw peak and 400-w average; the antenna had a gain of about 9 dBi. The target detected was the approach resonant waves in a range gate 20 nmi wide and centered on a 20-nmi distance from the transmitter signal.

(S) Figure 14 shows photographs of three of the displays made during the tests. The Δf-vs.-R picture gives doppler in Hertz against range, where the leading edge of the first signal from Boulder is set at zero. Thus the large signal at C (carrier referenced as zero) in doppler and starting at zero R is principally the transmitted signal plus perhaps nearby returns from fixed targets. The signal seen at about 90 nmi is the transmitted signal received by another (and weaker) mode. The signal of interest is at about +0.4 hz and is interpreted to be from the approaching resonant waves on the Bay - probably those near the receiving antenna and nominally in line with the two antennas. The plot of doppler (Δf) vs. time before 1939Z comes from a 20-nmi-width range gate centered on 20 nmi. This doppler-time record shows some frequency drift (such drift being transmission-path-induced) and providing an example of frequency dispersion. The amplitude-vs.-doppler (A-Δf) picture shows an analysis made at -4 minutes from the doppler-time record.

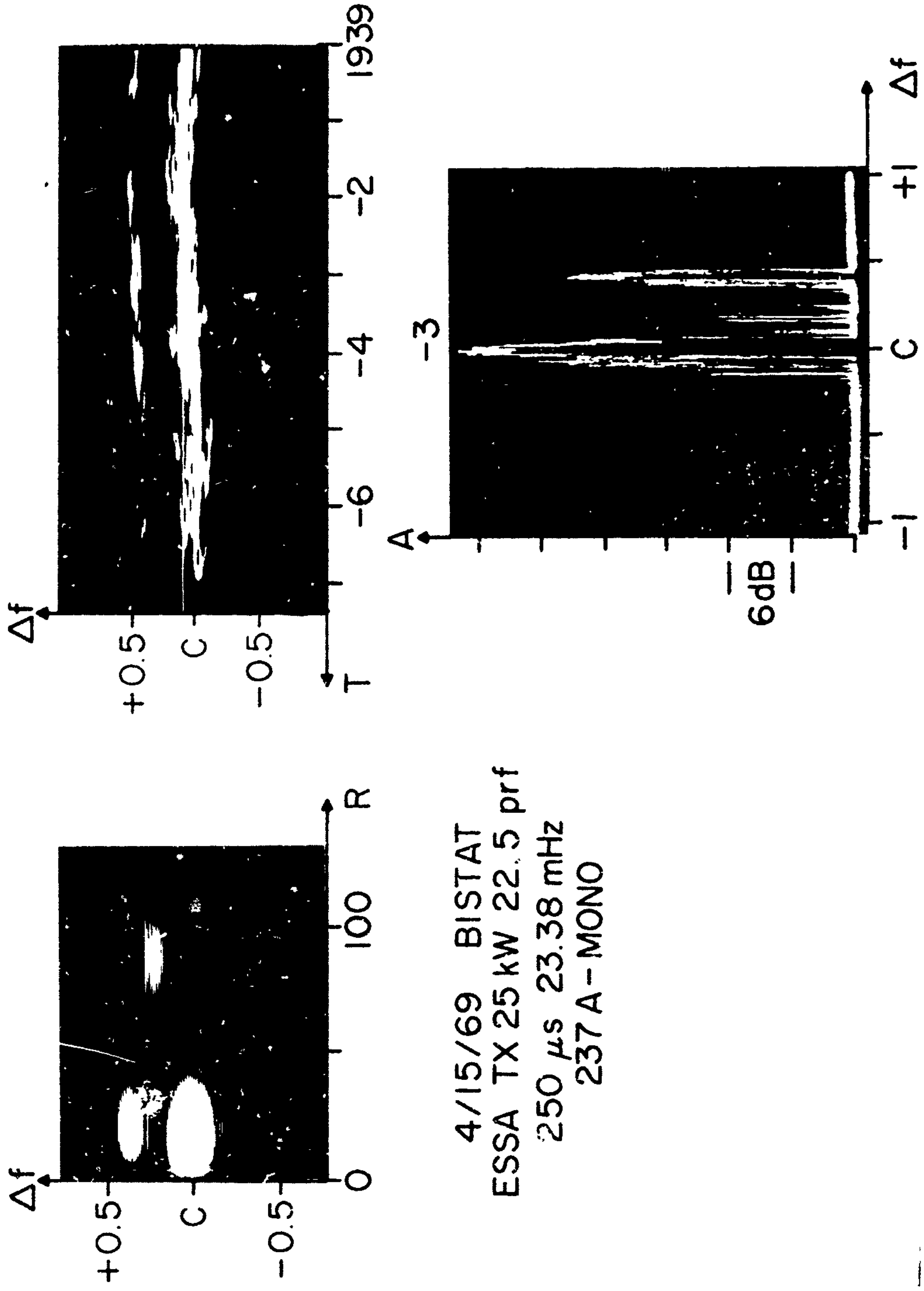


Figure 14 - Bistatic test (S)

(S) This test indicates that several facets of bistatic potential can be investigated with the equipment on hand, especially when ESSA puts in service a higher-power radiator. Several aircraft tracks were noted, sky-wave illuminated and line of sight to the receiver. Therefore, higher power should permit studying the possibility of removing some ionospheric effects by correlating target signals with the transmitted signal.

VII. DISCUSSION OF SWR-REQUIRED FEATURES (U)

(S) The primary tasks are to establish SSM and ASM detection feasibility and required radar design criteria as in monostatic surface-wave radar. It would be better if more observational data were in hand; however, in the interest of timeliness a radar capability will be extrapolated from the tests described herein.

(S) For the S2 aircraft test the average radiated power was 47 dBw, the antenna gains G_t = 10 dBi and G_r = 5 dBi giving PG_tG_r = 62 dB. This test was used to estimate that an SSM or ASM should be detectable over the ocean at 55 nmi with a radar optimally designed using PG_tG_r = 62 dB.

(S) Tacit in this estimate were the assumptions that the missile target would be only 10 dB smaller than the S2 aircraft, more processing gain could be used on the missile than was used on the S2, and the S2 observations were clutter-limited, not noise-limited. Since the noise interference level was probably 10 to 30 dB below the target level, the estimated performance is thought to be conservative. Figure 15 is a ground-wave transmission vs. range curve over the ocean. The performance capability estimate of 55 nmi for PG_tG_r = 62 has been used to fix a PG_tG_r scale. Using this scale the following table can be constructed:

PG_tG_r (dB)	Det Range (nmi)
60	52
62	55
71	70

Consider the radiated power of the test (47 dBw or 50 kw average); a resonant monopole, G_t, 5 dBi; and four well-spaced loops or dipoles giving an estimated directive gain of 8 dBi. The resulting PG_tG_r product 60 dB is sufficient for over 50-nmi detection range. This manner of configuring the radar is somewhat similar to the Keltec approach(6); insofar as the antennas are concerned they could be emplaced on ships as small as a DL; however, the monopole (omnidirectional) radiator would be a dominant topside feature. Figure 16 gives an antenna and hull sketch where the monopole might be 30 feet for 10-MHz operation.

(S) A similar approach to the antenna design can be discussed. Consider putting on a ship four resonant dipoles of height up to 60 feet, and

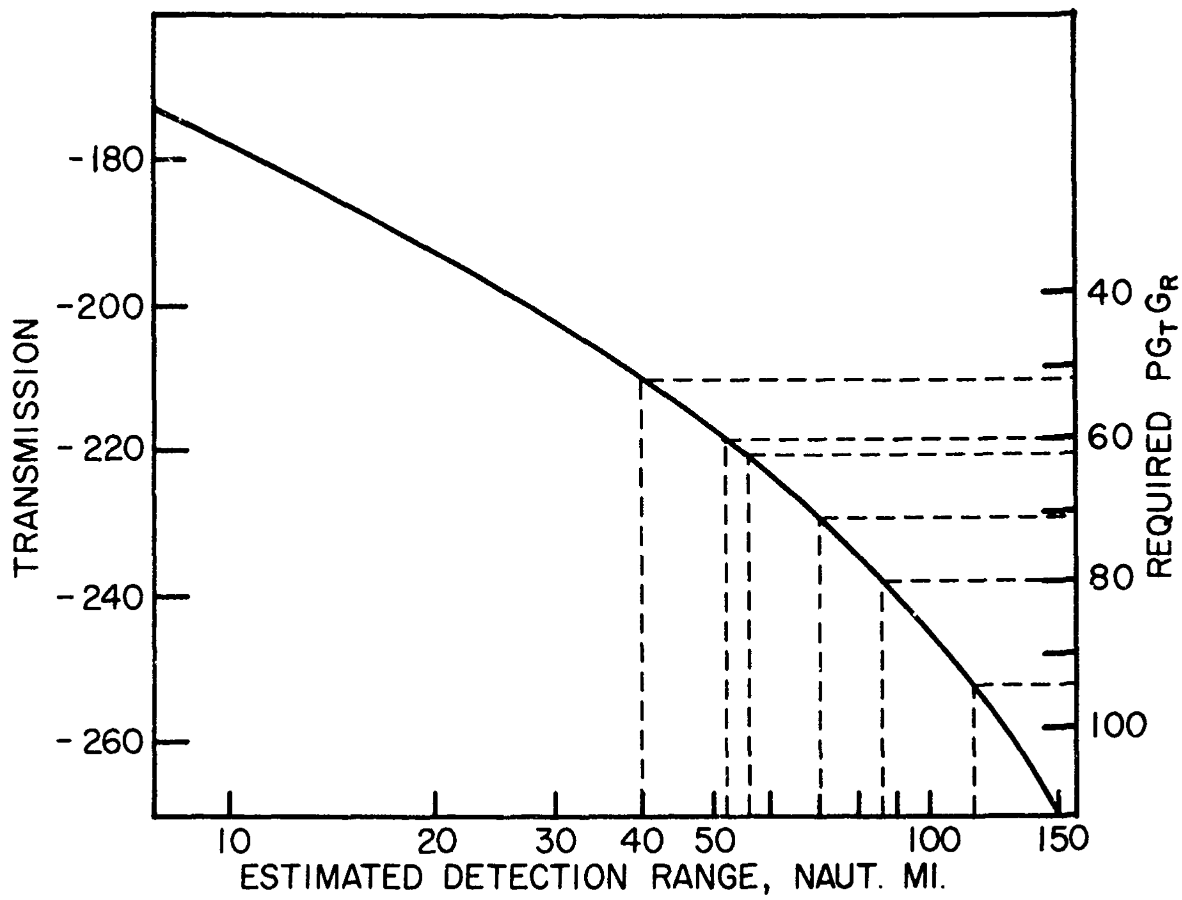


Figure 15 - Ground wave transmission versus range. Left ordinate is a fit of PG_t PG_r based upon observations of the S2 aircraft. (S)

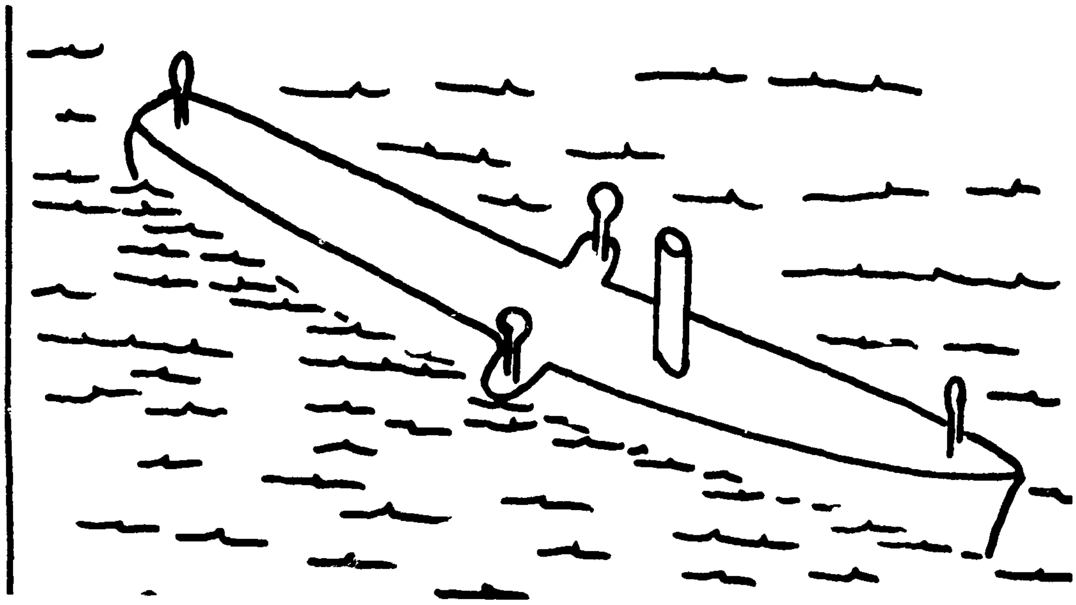


Figure 16 - A hull and antenna ccnfiguration (S)

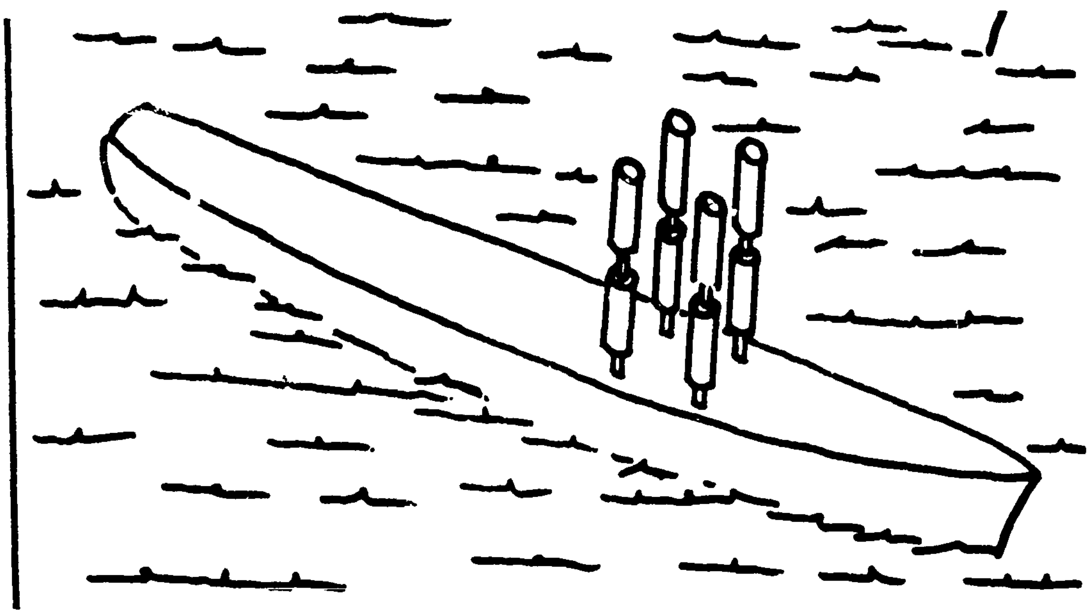


Figure 17 - A hull and antenna configuration (S)

spaced 25 feet (at least $\lambda/4$) apart. A sketch is shown of the hull and antenna configuration in Figure 17. Such an antenna might realize 12 dBi gain. Again, using the 47-dBw power, $PG_tG_r = 71$, and a detection range of 70 nmi is predicted. This system would need to coarse-scan (90^o sectors) to use the postulated PG_tG_r, and detections would have to be made on the basis of these broad beams. Fine azimuth determination (estimated $\approx 1^o$) could be performed after detection. Of course, all of this line of reasoning is based upon a small amount of 10-MHz experimental data; however, it is believed that in Figure 15 the power and antenna-gain requirements of surface-wave radar are conservatively depicted. Longer-distance performance will require larger antennas, and Stine[7] gives some possible forms plus equipment weight and volume estimates.

(S) So far the showy part of the radar, transmitter power, and antenna have been discussed, and an effective receiving processing system has been assumed. Figure 18 can be used to deduce what may be required to handle received signals. In this figure the clutter radar area (dB/m^2) is plotted versus range for an omnidirectional antenna and a 10-nmi range cell, and for a 90^o-azimuthal beamwidth antenna (quarter) and a 10-nmi range cell, and for a 90^o antenna with a 1-nmi range cell. If the desired target is 1 m^2, the σ_c scale reads directly in average-clutter-to-signal ratio (remember that peak values will be somewhat larger). The linear ranges that have been achieved in receiver design and those shown in Figure 2 indicate that the necessary receiver can be achieved. The doppler and direction-finding processor with required characteristics does not exist, but it is felt that a suitable processor can be realized digitally.

VIII. DISCUSSION OF NAVAL APPLICATION (U)

(S) The specific advantage that HF radar offers is long-range detection of aircraft and missiles, no matter how low the altitude. The two methods of getting over the horizon are sky-wave and surface-wave propagation. Therefore, consider the following:

1. Land-based sky-wave radars specifically for naval use, furnishing detection at 500 to 2000 nmi from the radar.

2. Additional tasks placed upon sky-wave radars built for other purposes, such as CONUS defense against nuclear attack by aircraft and missiles.

3. Sky-wave radar mounted on a mobile sea platform, positioned as required to furnish surveillance for fleet units. The radar could be 700 to 1500 nmi from the operating area and would furnish OTH survey around the unit for a one-hundred-mile radius.

4. Surface-wave radar mounted on fleet units intended to provide OTH coverage out to 100 nmi.

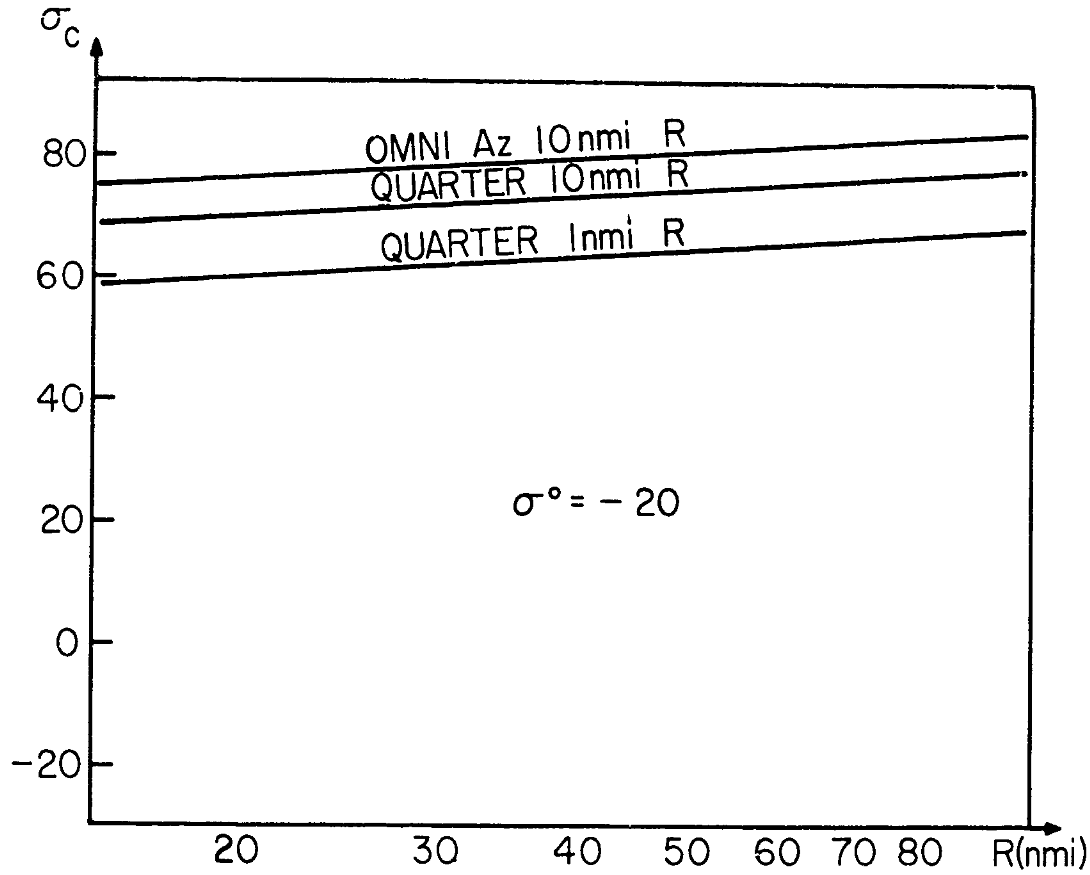


Figure 18 - Clutter radar cross section (db/M^2) versus range (nmi.) (S)

5. A bistatic mix of Items 3 and 4 that uses the sky-wave radar for target illumination and passive detection by surface-wave ship-mounted receiver.

Item 1, land-based radars, for exclusive naval use may be a questionable proposition on the basis of cost. Item 2 is desirable and requires the Navy to keep abreast of HF application, to know what is possible and to make the needs known early in any OTH deployment program. Item 3, a mobile seaborne OTH radar platform that can provide coverage at distances, say, from 700 to 1500 nmi, would be quite valuable. Such a mobile radar could be positioned to cover a fleet operating area and provide fleet units, by a radar data link, with OTH aircraft and missile-detection capability. Item 4 is the subject of this paper, and the general findings are that surface-wave radar can provide OTH detection of ships, airplanes, and missiles. Item 5, bistatic sky-wave illumination and surface-wave detection by "quiet" fleet units, is a technology that needs attention. This method offers a desirable feature in that the fleet unit can be quiet and still perform its own target detection.

Also, there is real, but not yet demonstrated, capability for detecting surface targets in addition to aircraft and missiles. It is felt that the sky-wave illuminator should always function as a monostatic radar and transmit its findings to the fleet unit being serviced, as in Item 1.

APPENDIX A

The Chesapeake Bay

E. W. Ward

(U) The Bay needs some description as the conduction surface for surface wave propagation. It is a confined body of water, with much of the area quite shallow; thus the wave composition will not be identical with that in the open sea, and the Bay backscatter coefficient can be expected to be smaller on the average. The salinity of the Bay varies throughout the year, being a function of rainfall on feeding rivers watershed. A conductivity description can be derived from E. D. Stroup and R. J. Lynn (Atlas of Salinity and Temperatures 1952 - 1961, Johns Hopkins University Chesapeake Bay Inst.). Salinity data are in the form of Fig. A1 where the radar site is at the circled cross and the path to be studied is drawn with 10 nmi ticks. Figure A2 shows average surface salinity starting at the radar site and going down the Bay on the path of Fig. A1; the table shows the corresponding surface temperature.

Surface Temperature °C

Spring	Summer	Fall	Winter
13	27	13	3

Conductivity as a function of salinity, parametric in temperature, is given in Fig. A3. These data can be used to give average expected conductivity versus distance from the radar as shown in Fig. A4. Considering that the winter and spring of 1969 had less rainfall than normal, 2 mho/m is selected as an average conductivity to use in the computations; ground wave 2-way loss for this selection is given in Fig. A5. Figure A6 is an estimate at the illuminated area by ground wave.

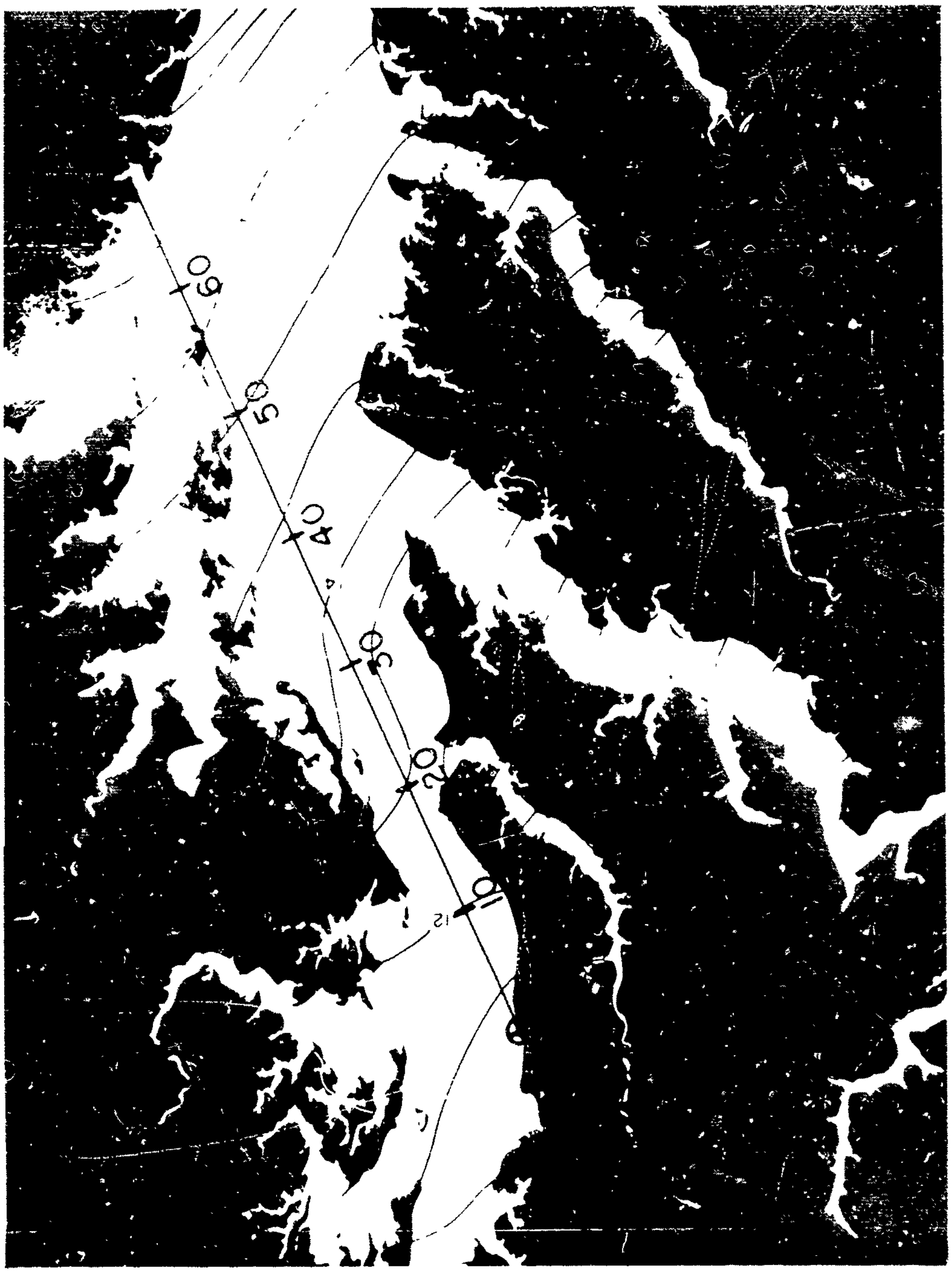


Figure A-1 - Area of salinity data (U)

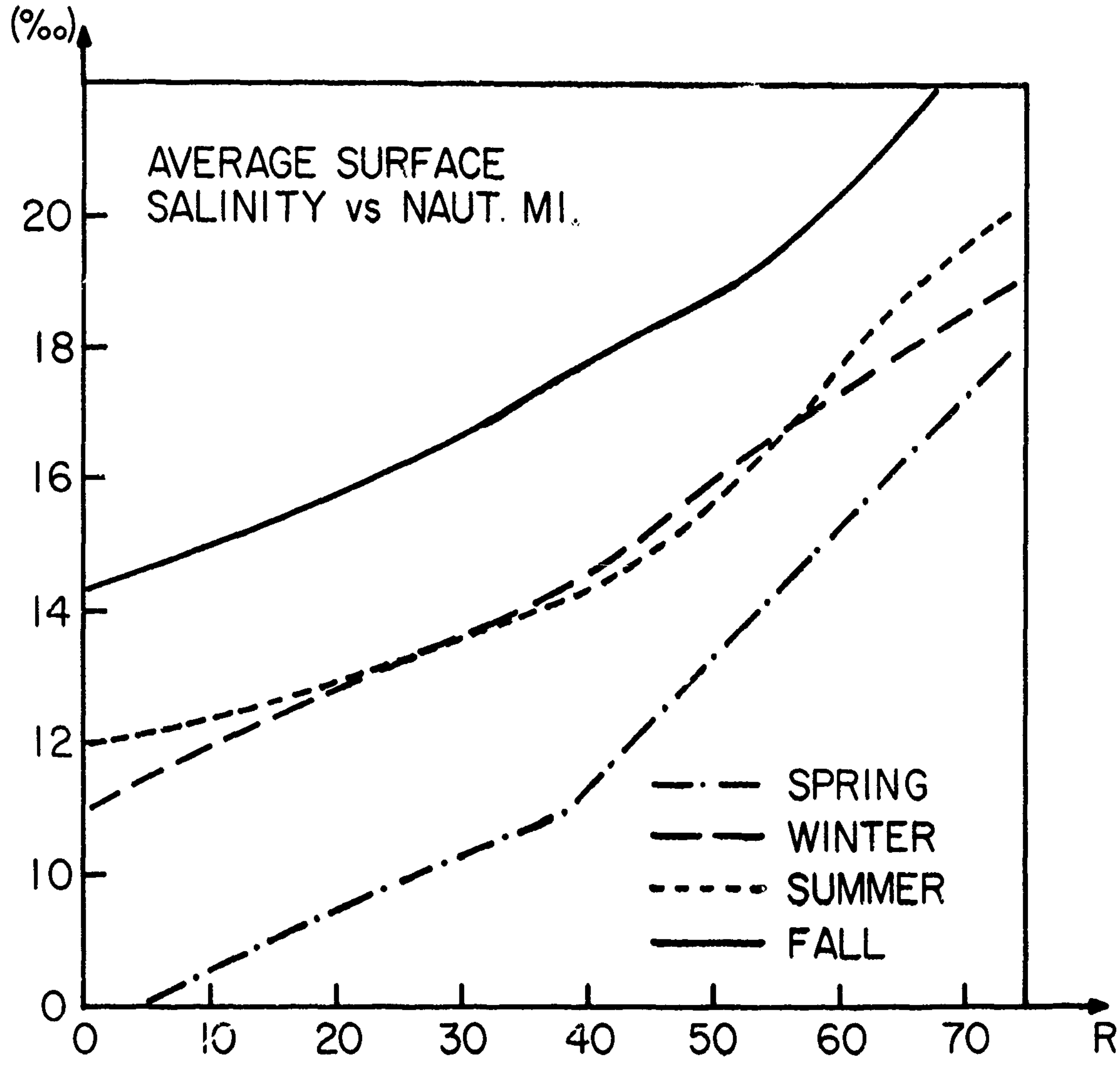


Figure A-2 - Average surface salinity (U)

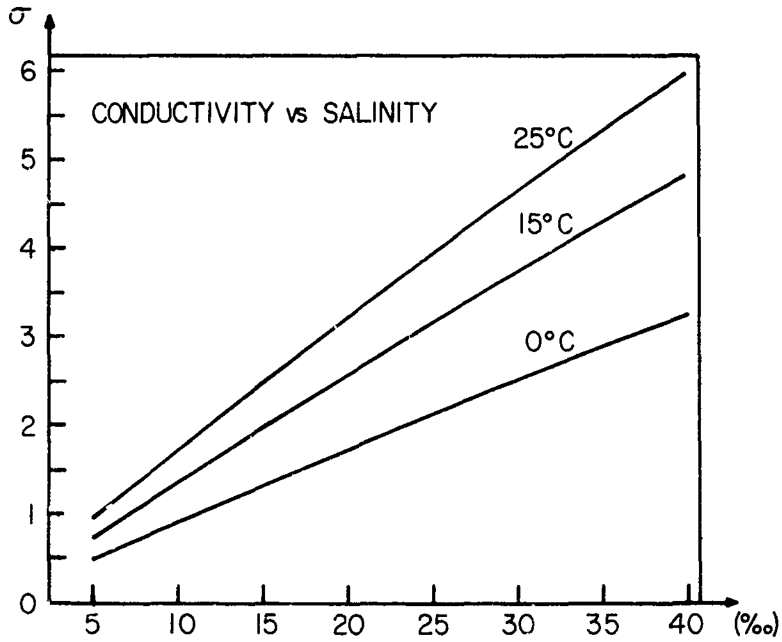


Figure A-3 - Conductivity versus salinity as a function of temperature (U)

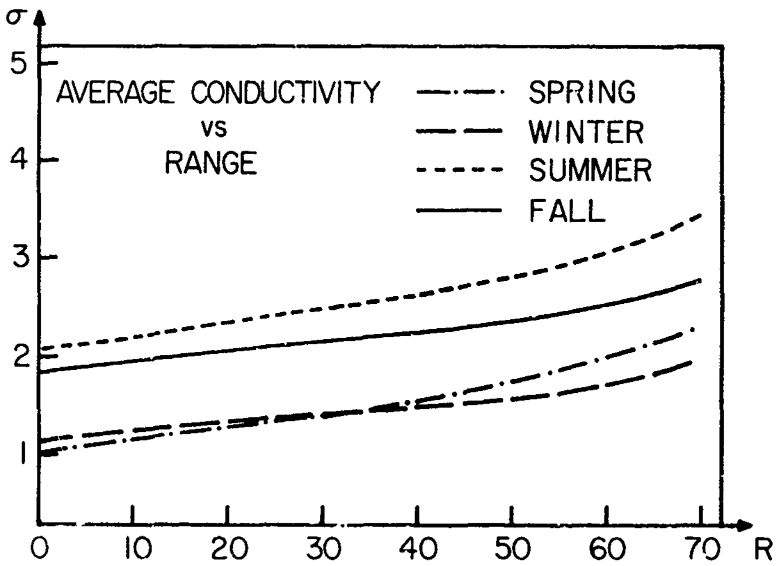


Figure A-4 - Average conductivity as a function of distance (U)

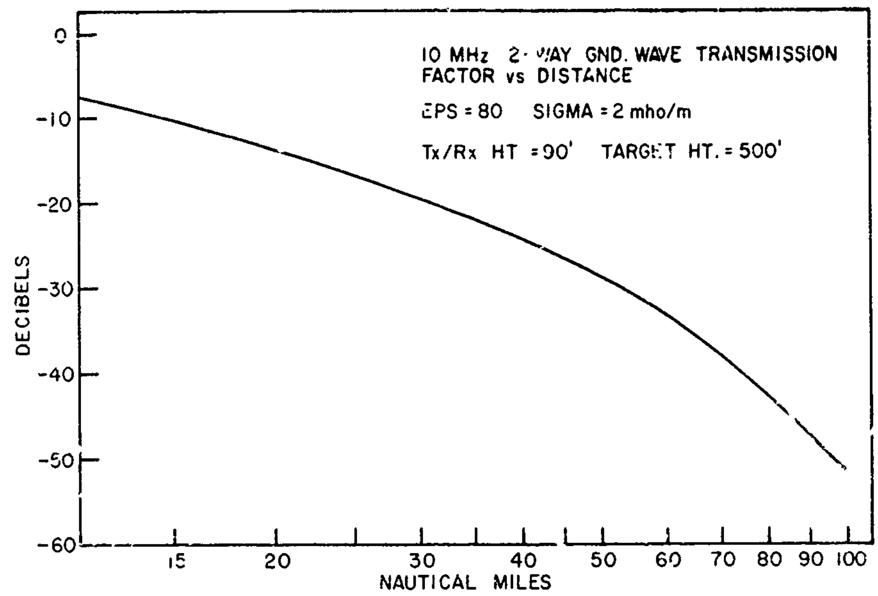


Figure A-5 - Two-way ground wave signal loss as a function of distance (U)

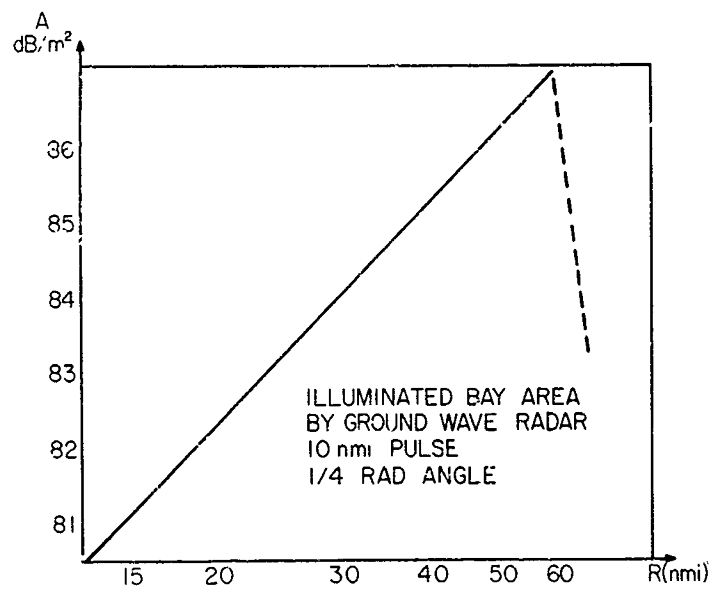


Figure A-6 - Illuminated Bay area versus range. The pulse length was taken as 10 nmi. and the azimuthal angle as one fourth radian; at 60 nmi. the Eastern Shore causes the area to start diminishing with range. (U)

APPENDIX B

Field Strength and Gain Measurements of FTM Antenna (U)

F. E. Boyd

(U) Gain of the FTM antenna was measured by comparison with a monopole. For this purpose a special monopole was set up over water about 150 feet from shore. The monopole base is about 30 inches above mean tide level and eight ground plane wires 100 feet long provide continuity to the water. The length of the monopole was adjusted to quarter-wave resonance at 10.087 MHz. The impedance was then measured after which a power input was computed from the measured r.f. current squared multiplied by the resistance. This was checked against a directional coupler watt meter and found to be in agreement. Although the power input measurement is not necessary for the gain comparison, it does allow an evaluation of the propagation path and this can be done with little additional effort. Conductivity measurements of Chesapeake Bay surface water taken on May 2, 1969, a time nominally coincident with the field strength measurements is given below:

Location	Conductivity (MHO/M)	Temperature (°C)
Breezy Point	1.197	15.0
Cove Point	1.672	15.2
Taylor Island	1.904	15.0

These locations are all less than 20 nmi down the Bay with Taylor Island being the one measurement on the eastern shore. Some typical measurements are given below:

Distance (KM)	Field Strength (MV/M)* Measured	Theoretical Free Space	Meas. F.S. - Theor. F.S. (dB)	GND. Wave+ Loss (dB)	Error (dB)	Gain (dB)
26.1	8.3	12.	-3.2	-4.07	+0.9	3.5
32.2	5.44	9.6	-5.0	-5.02	0.0	4.5
45.1	5.6	6.96	-1.9	-7.01	+5.1	3.0
53.9	1.95	5.32	-9.5	-8.34	-1.2	6.5

*Field strength is millivolts per meter for one kw radiated.

+Computed from an algorithim written by I. Gerks using 2 mho per meter surface conductivity.

In this table the column "error" gives the difference between the previous two columns; essentially this is the measurement error if we consider the ground wave loss computation correct. The column marked "gain" is the

relationship between the field strength produced by the two antennas. An average of nine such readings gave a gain figure of 4.7 dB; the absolute gain is obtained by adding the gain of the standard monopole (5.15 dB) giving 9.86 dB.

(U) Additional measurements beyond 100 km were made but appeared to have been contaminated by sky wave. This was confirmed when the critical frequency was found to vary between 9.1 and 9.8 MHz during the measurement period. While these measurements generally seemed in accord with expectations, no data are presented because of the large fluctuations obtained at these distances.

(U) It was observed that a shadow of the FTM antenna (relative to the monopole) is evident between Breezy Point and Cove Point along the western bay shore. This undoubtedly occurs because the monopole is located about 400 feet east of the FTM antenna and is not blocked from view as much at Breezy Point. Also, it was noted that field strengths were slightly higher on the water side of a shore line compared to the land side.

(U) Another method can be used to compare the FTM antenna with the reference monopole. The accompanying figure is an example: the amplitude of the approach resonant wave echoes are given as a function of distance, transmission is by FTM antenna and reception by both FTM and the monopole. These results can be seen to agree with those earlier described; this method does not permit a path loss determination.

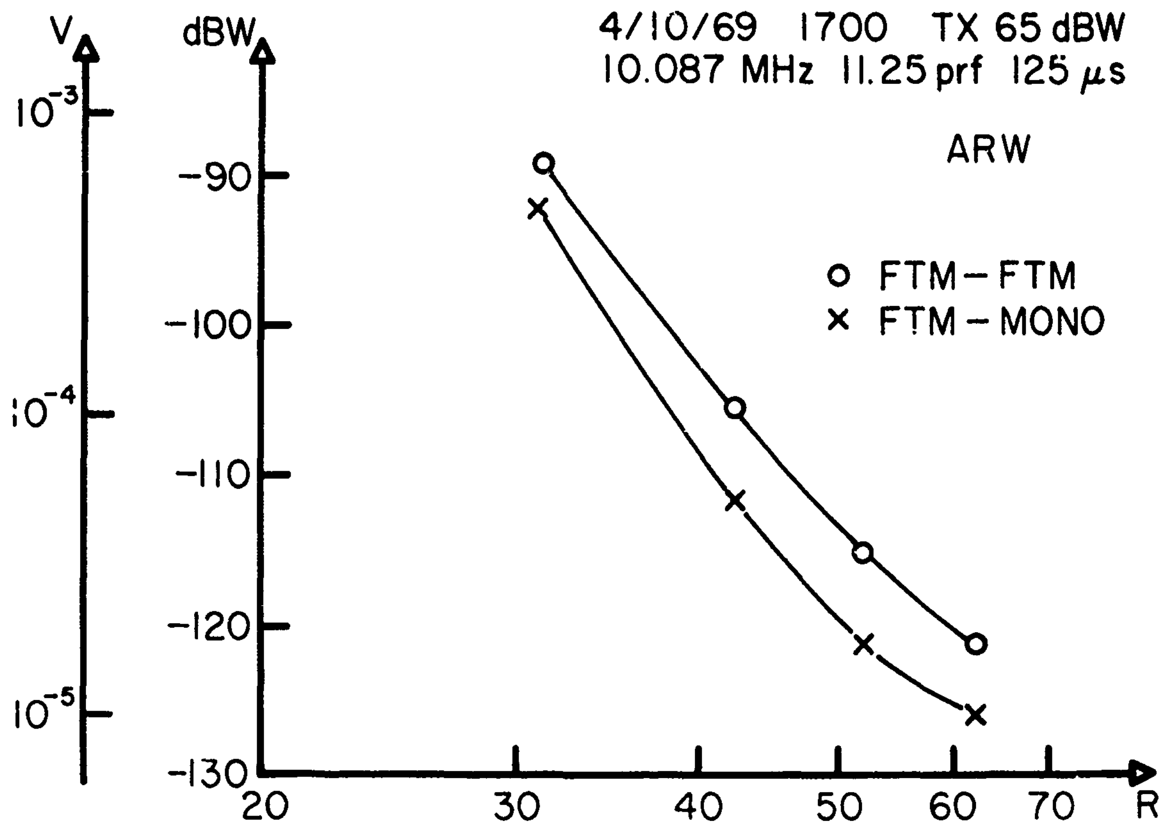


Figure B-1 - Received signal versus range using the FTM and the MONO. The FTM was used for transmit and the target was the approach resonant Waves on the Bay surface. (U)

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13 ABSTRACT

(SECRET)

Aircraft, ship, and clutter echoes have been studied using surface-wave propagation on the Chesapeake Bay. These studies show that coherent pulse doppler methods can be used for surface target detection. Required radar features for several applications can be estimated.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Shipboard surface-wave radar						
High-frequency radar						
Bistatic surface-wave radar						
Passive area surveillance						
High-frequency radar cross section						

MEMORANDUM

20 February 1997

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Memo: 1251, 1287, 1316, 1422, [redacted], 1500, 1527, 1537, 1540, 1567, 1637, 1647, 1727, 1758, 1787, 1789, 1790, 1811, 1817, 1823, 1885, 1939, 1981, 2135, 2624, 2701, 2645, 2721, 2722, 2723, 2766. Add 2265, 2715.

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